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CHALLENGES IN MISSILE LIFE CYCLE SYSTEM ENGINEERING

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U.S. ARMY MISSILE COMMAND

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13. ABSTRACT *(Maximum 200 Words)*

Increasingly complex and costly weapon systems, combined with declining defense budgets, require innovative approaches for weapon system acquisition and for missile life cycle engineering. These innovative approaches are discussed under three major headings: Weapon System Acquisition Challenges, Missile System Life Cycle Reliability Challenges, and New Technology Challenges.

The Weapon System Acquisition Challenge Section discusses Secretary Perry's acquisition reform initiatives. Two initiatives most extensively covered are Performance Based Contracting (PBC) and the Single Process Initiative (SPI).

The Missile System Life cycle Reliability Challenges concentrate on the missile and rocket Stockpile Reliability Program (SRP), particularly the shelf-life and surveillance testing aspects. The shelf-life program is explained and the cost benefits are presented

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(billions of dollars of cost avoidance over a 30-year period). The surveillance testing program benefits are discussed, particularly with regard to detecting defective hardware and enhancing our soldiers''warfighting capability.

New Technology challenges include simulation, remote monitoring systems, and plastic encapsulated microcircuits (PEMs). Details are provided on MICOM's PEM storage assessment program, actual aging program, accelerated aging model, and joint research programs.

Our 21st Century soldiers must be the best equipped soldiers in the world. The acquisition reform and technology initiatives discussed in this report can help achieve this objective. Our challenge is to implement these initiatives and apply the technological advances in a way that prevents any performance degradation. Our soldiers must have weapon systems they can bet their lives on!

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I. INTRODUCTION

Acquisition Reform, a term coined by the Department of Defense to describe the reformation of the military acquisition system, has been with us now for approximately three years. The beginnings of the acquisition reform initiatives were on 29 June 94, when the Honorable William J. Perry signed a memorandum (1) directing implementation of the recommendations in the "Report of the Process Action Team on Military Specifications and Standards, Blueprint for Change" (2). Since that time there have been many policies and guidance memorandums issued concerning the specifics of acquisition reform, culminating in an update of the DOD 5000 series in November 1996.

Prior to the official DOD policy being issued, the Army Materiel Command (AMC) traveled annually to its major subordinate commands (MSCs) to teach acquisition improvement initiatives to the acquisition work force. Annual training sessions, called Roadshows, have been conducted the past five years. The training continued in 1997 with Roadshow VI, which emphasized Acquisition and Logistics Reform.

A key purpose of the acquisition reform initiative is to take advantage of commercial processes and innovations. The military, once a major buyer of electronic parts such as microcircuits and semiconductors, now is only a minor player. In addition, the electronic market is extremely volatile, as demonstrated by the personal computer market where computers purchased only three years ago are practically obsolete. This situation is compounded since military hardware can take 10 to 20 years to be developed and fielded. Because of the rapid advances in the electronic industry and long development times for military hardware, newly fielded system may contain many obsolete components.

A potential solution to the obsolescence problem lies in the use of performance specifications. This allows the government to state its needs in terms of form, fit and function, and allows the contractor to develop the solution. With this approach, the contractor is not required to build a product from a fixed design that may contain obsolete parts, but may use the latest electronic parts and components available.

While the intentions of the acquisition reform initiatives are commendable, they are difficult to implement and present many challenges to Army buying commands. Some cautions were noted by Howard and Davis (3). For example, long term storage reliability is a critical requirement for a missile system. Missiles developed and fielded today must have the capability to be stored for 10 to 20 years, with only minor losses in reliability. In the past, the government relied on detailed technical data packages to define and build a system that would meet its storage and in-flight reliability requirements. With a performance

specification, the product may essentially be redesigned at the contractor's discretion. Hence, the inherent reliability of the fixed design, that was verified in qualification tests, no longer applies. Therefore, qualification of production hardware will be more complex and costly to verify achievement of all performance requirements including reliability. An effective stockpile reliability program will also be required to maintain surveillance of the various designs in the inventory.

New technologies have the potential to both help and hinder the process. For example, Plastic Encapsulated Microcircuits (PEMs), while cheaper and widely used in commercial products, have not yet been proven reliable for long term dormant storage of missiles. Micro Electro-Mechanical Systems (MEMS), Self Monitoring Advanced Remote Technology (SMART), and Missile Advanced Remote Monitoring System (MARMS) technology, when fully developed have the potential to provide an insight into storage environments that will help assure that storage reliability requirements are being met. These technologies will also help lower stockpile reliability testing costs and provide for remote monitoring of our missile assets. In the future, potentially from a centralized remote site, we will be able to know the exact conditions, such as the temperature, humidity, shock, and vibration that a missile experienced in storage.

The emerging field of simulation also offers potential savings in the area of testing. Simulation is currently being considered for use in Longbow missile system lot acceptance testing. These simulations have the potential to greatly reduce system cost and schedule impacts. Currently on HELLFIRE II lot acceptance testing, up to 12 missiles may be flown before a lot can be accepted. This assumes the lot is accepted on first submittal. If missile failures occur, there can be up to three submittals. These are assets that are destroyed and thus cannot be fielded. At a cost of roughly $47,000 dollars per missile, the acceptance of a lot could potentially cost over half a million dollars. Simulation, in combination with live firings, can reduce the number of missiles that must be fired to prove lot quality. Considering the cost of a Longbow missile, cost avoidance will be in the millions of dollars.

II. WEAPON SYSTEM ACQUISITION CHALLENGES

The Department of Defense (DOD) acquisition reform initiative was developed in response to the declining military budget. As presented by Mr. Dale Adams during Roadshow VI, the overall Army budget has declined 42% since 1985, with the hardware procurement budget dropping 66% and the sustainment budget dropping 32%. There are numerous reform initiatives, ranging from performance based contracting to reinvention laboratory and the single process initiative (SPI). Each of the various initiatives offer potential cost savings and performance improvements, but implementation of acquisition reform has created many challenges.

A. Performance Based Contracting (PBC)

Performance based contracting was officially endorsed in the latest version of DoD 5000.2R(4):

> "In solicitations and contracts, standard management approaches or manufacturing processes shall not be required. Performance specifications shall be used when purchasing new systems, major modifications, and commercial and non-developmental items."

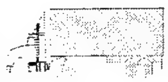
With those simple words, the Department of Defense completely changed the contracting approach for procuring military hardware. In the past, the Army buying commands developed a contract statement of work that defined exactly what was to be procured, and how the item was to be manufactured. With this type of contract, once a system was developed and fielded, the contractor had little flexibility to use innovative processes, procedures or components without approval from the government. The use of PBC with performance specifications gives the contractor the desired flexibility. Figure 1 provides some cost saving examples where PBC was used.

Army MIA2 Tank Commander's Thermal Viewer

Unit price reduced from $300K to $225K

Automotive Tube Fittings

SAE J512 vs MS51674 and MS51883. Unit costs reduced 37%, 68% and 50% for three different parts



Commercial Automotive Light Bulbs

Commercial Light Emitting Diodes replace light bulbs on Army Trucks. Lifetime extended from 1,000 hours to 100,000 hours. Development phase alone saved $50,000.

SATCOM Spares

Awarded over $10 M in mobile satellite communications spares requirements. Cut ALT/PLT In half, saved $3.0M.

Source: Roadshow VI presentation by Mr. Adams, AMC

Figure 1. Performance Based Contracting (PBC) Examples

The technique of Performance Based contracting (PBC) was a topic discussed during Roadshow VI at the MICOM Sparkman Center in Feb 1997. Performance based contracting requires the government to state its materiel needs in terms of form, fit, and function. The government does not provide the contractor with the solution, as in the case of detailed technical data packages, but allows the contractor to use his own engineering expertise to develop hardware which will meet the performance requirements and applicable interface criteria. Potential payoffs from this type of contracting approach include: (1) modernization of hardware through spare part procurements; (2) reduction of the extensive component obsolescence problem; (3) lower hardware cost; (4) less schedule and delivery slippage; (5) leveraging from the commercial world; and (6) reduction of the government overhead.

While holding promise for improved efficiencies and cost reductions, the use of PBC has many challenges. Performance based contracting assumes that the government can select highly qualified and reliable contractors to perform the required tasks. Using performance specifications without strong contract requirements, especially when contracting with mediocre contractors with little or no engineering expertise, is a sure way to failure. Request for proposals (RFPs), using PBC must have a well written statement of work, along with strong L (Instruction to the bidder) and M (Evaluation criteria) contract sections. With the direction of DOD 5000.2R to not call out government specified standard manufacturing and management approaches or processes, the selection criteria that is specified in the contract must insure that the government contracts with only the best contractors. In the past, the government worker used government specifications, standards, or handbooks to

evaluate a contractor's approach. Now they must rely on their own engineering experience and judgment and knowledge of commercial specifications and standards. This manpower intensive approach can be used for new hardware design and manufacturing but does not work as well for spare and repair part buys because of their large number of buys and the lower dollar value of most contracts.

The use of performance specifications (PS) comes with its own set of hazards. The PS must have sufficient detail to fully describe the form, fit, and function requirements of the item. In most cases, the PS will have to be considerably more detailed than the old product specifications since the PS will have to be a stand alone document, without tiered requirements. Overall, a PS should not contain any how-tos. However, Section 4 (Product Verification) of a PS is the exception to this rule. Section 4 must require enough inspection and test information to ensure that the item meets specified requirements.

When using PS, properly managing the configuration of the item after it has been qualified is essential. Although the government no longer has configuration control lower than the PS level, the government must still have an insight into any significant changes that occur after item qualification, such as changes to components, materials, processes and hardware environmental stress screening. The need for re-qualification cannot be adequately assessed without insight or visibility into changes to the qualified configuration baseline. When significant (based on the complexity or volume) changes have been made to the hardware, software, or components, the initial qualification will have to be revisited to determine if re-qualification is required.

Using performance specifications does provide for the modernization of hardware through spares. However, the cost may be higher than expected, and the payoff considerably lower. The approach being taught today assumes, through competition, contractors will use the flexibility of a performance specification to update the hardware with the very latest and best performing parts. While that may be true, the contractor must still design and qualify each new part, or the assembly, which could be costly and time consuming. In addition, the newly designed component must work with the next higher assembly, which may be 10 to 20 year old technology. The typical quantity of spare parts being procured must be considered. How much time and engineering effort is the contractor willing to invest to sell the government 10-30 (the typical quantity for a spare part buy) modernized spares?

B. DOD Single Process Initiative (SPI)

The Single Process Initiative SPI)is another acquisition reform initiative that is designed to save the government money and time. The SPI attempts to accomplish this task by standardizing the DOD required processes, procedures and practices within a contractor's facilities(5):

> "The objective of the Single Process Initiative is to allow contractors to use best commercial practices and in so doing, eliminate multiple, redundant, and non-value added requirements. "

Previously, a contractor who manufactured hardware for the Air Force, Navy, and Army may have had three or more different requirements for government dictated processes, procedures and practices in the same facility. Figure 2 provides an example of the types of processes being standardized for MICOM contractors.

- Quality Program
- Parts Receiving
- Engineering Change Proposals
- Parts Control
- Soldering
- Hybrid Microcircuits
- Reduced Test & Inspection
- Engineering Drawing Practices
- Material Review Board Practices
- Calibration Systems

Figure 2. SPI Technical Processes

The single process initiative brings representatives from the three services together, along with the affected contractor, to develop standard military requirements for the contractor's facility.

The first SPI effort was conducted at Raytheon Company on 32 SPI proposals for the reinvention laboratory program. As part of these proposals, Raytheon identified over 13 million dollars per year that could be saved. Figure 3 provides the number of

proposals Team Redstone submitted, contracts affected, and programs impacted since the inception of SPI.

- **11 Companies Have Submitted 103 Proposals**
- **362 Army Contracts Affected**
- **Programs Impacted - PATRIOT, HAWK, BAT, EFOGM, TOW, ITAS, IBAS, JAVELIN, STINGER, BFVS, BAT, TMDE, AGMS, ATACMS, MLRS, PAC-3, STINGER Moving Target Simulator**

Figure 3. SPI Proposals

Overall, after many technical discussions and meetings and reviews, the majority of these proposals have been given technical concurrence by the three military services and the affected contractors.

The implementation of the SPI presents challenges that are different than performance based contracting. Getting technical agreement from an integrated product team (IPT) consisting of representatives from the contractor, Defense Contract Management Command, and from each of the Armed Services, is extremely difficult and time consuming. Figure 4 outlines the technical approach used for IPTs where MICOM Research Development and Engineering Center (RDEC) had the Army technical lead. Through a dedicated team effort, numerous IPTs worked and resolved issues ranging from contract delivery efforts to overall quality requirements for the facility. The teams that worked these proposals found that it was essential to be open minded and flexible. The team membership changed as little as possible to ensure a consistent approach at each facility. A major lesson learned by one of the contractor's was that (6):

> "A conscious effort to ensure effective communication is required of all participants. Senior contractor, PEO, program, local DCMC, and DCAA management work together to quickly resolve issues and actively encourage all IPT members to rapidly reach closure for their process."

- Government/Industry Teaming
- IPTs (Air Force, Navy, Army, DLA, with a Contractor Chairman)
- ARMY IPT Members from RDEC (48 Technical Proposals)
- Both On-Site and Off-Site Communications
- Technical Negotiations to Reach Common Ground
- Coordination with PEOs, PMs
- Required Compromise from Everyone
- Technical Agreement Reached by IPT
- Block Mod Proposals Developed by Separate Pricing/Contract Teams
- Block Mods Reviewed for Approval by RDEC IPT Members

Figure 4. SPI Approach

The major failure of the SPI to date is the lack of actual cost savings. From the roughly 13 million dollar yearly savings originally proposed by Raytheon, "the Army's share of the savings was $1.5 million (5)." Thus far, the same holds true for all of the other SPI efforts. Most cost reductions projected today are actually in the out-years as cost avoidance expected on future contracts. Even with these small beginnings, government and industry agree that there will be savings on future contracts as a result of the SPI initiative.

The various acquisition initiatives have great potential to improve the way the military contracts for materiel. However, along with this great potential is the formidable task for the buying commands to properly institutionalize the initiatives into wise business practices. Each initiative, to include SPI and performance based contracting, has pitfalls that must be avoided if the Army Missile Command (MICOM) is going to continue to have the latest technology and highest equipment readiness rate in the world.

III. MISSILE SYSTEM LIFE CYCLE RELIABILITY CHALLENGES

The heart of MICOM weapon systems is the sophisticated electronics that provide the capability to rapidly detect, track, and intercept enemy targets. To meet advancing threats, weapon system electronics have become much more dense, sophisticated, and complex. These new components may be more sensitive to the effects of temperature, mechanical stress, and chemical corrosion. The missile system hardware must be instantly capable of launching and must be highly reliable, not only at delivery, but also after transportation, handling, and 10 to 20 years of dormant storage in harsh environments worldwide.

To achieve high reliability for missile systems, MICOM has stressed the requirement for high reliability soldering and parts, process controls, additional screening of selected microcircuits, and environmental stress screening (ESS) of printed circuit boards and higher level assemblies. Data gathered over a period of years verifies that this design and manufacturing approach, along with processes that find and fix defects at the lowest level of manufacturing, increases yields and reduces the system total life cycle cost as a result of the increased hardware reliability.

Prior to the Army implementation of Dr. Perry's memorandum, MICOM used tailored military specifications (MIL-SPEC) and standards to ensure that these high reliability, high quality practices would be used to design and build missile system hardware. Now we must carefully transition to the new way of doing business, which is primarily a cost cutting measure emphasizing the use of commercial specifications and parts. One key concern is the use of commercial PEMs in our missiles that require 10 to 20 years of storage. This concern will be addressed in the section on New Technology Challenges. Thorough, regular assessment of missile stockpile reliability is even more crucial with plastic parts in the missiles.

A. Stockpile Reliability Program (SRP)

The high cost and long life of missile systems make it necessary to have a comprehensive stockpile reliability program (SRP)for our U.S. Army missiles, as well as for Army missiles used by the Marine Corps, and missiles sold to foreign military sales (FMS) customers worldwide. The SRP program combines functional testing, laboratory testing, and missile flight tests to assess the condition of the stockpile and to make shelf life decisions. Functional tests are performed by surveillance vans used worldwide for smaller missiles (e.g., STINGER and HELLFIRE), and by fixed facilities for the larger missiles (e.g., PATRIOT and ATACMS missile facilities). Defective missiles are purged from the inventory, repaired, and returned for use.

For the small "wooden round" missiles there is no functional testing by vans or missile facilities. Only destructive testing is possible. Therefore, the SRP program uses missile teardown with component testing and flight tests to assess the reliability of these "wooden rounds", and to make missile shelf-life decisions.

B. Missile and Rocket Shelf Life

The stockpile functional test, laboratory test, and flight test programs provide the data for missile shelf-life extension decisions. Initial shelf-life requirements have ranged from 5 years, for the TOW missile, to 10 years for the MLRS rocket. By having a comprehensive functional, laboratory and flight test program these shelf lives have been extended to 22 years for the TOW and 15 years for the MLRS. These and other shelf life extensions (Fig. 5) result in billions of dollars of cost avoidance for procurement or rebuild costs that would have been incurred based on initial shelf life predictions/requirements. The SRP costs and cost avoidance are summarized in Figure 6.

SYSTEMS	INITIAL PREDICTION	CURRENT PREDICTION
HAWK MTR	5 YRS	20 YRS
TOW/ITOW	5 YRS	22 YRS
TOW 2B	10 YRS	10 YRS
HELLFIRE	10 YRS	13 YRS
SHILLELAGH	5 YRS	28 YRS
DRAGON	5 YRS	23 YRS
DRAGON II	5 YRS	9 YRS
PATRIOT	5 YRS	10 YRS
STINGER Basic	10 YRS	16 YRS
MLRS	10 YRS	15 YRS
CHAPARRAL WHD	10 YRS	20 YRS
TOW2/TOW2A	10 YRS	15 YRS

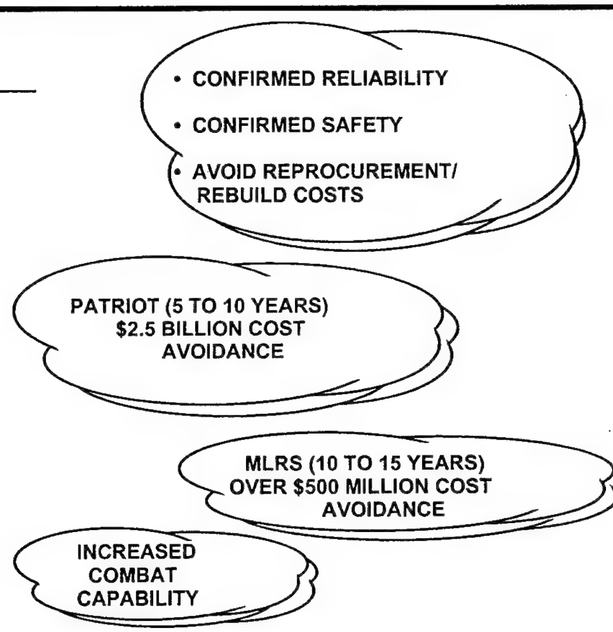


Figure 5. Shelf Life Extensions

SYSTEM	SRP COST	COST AVOIDANCE	COST AVOIDANCE RATIO
SHILLELAGH	19.6 M	687.2 M	34:1
HELLFIRE	5.4 M	813.1 M	150:1
TOW	7.5 M	1,345.0 M	178:1
DRAGON	6.4 M	294.7 M	45:1
HAWK	65.1 M	217.9 M	2:1
CHAPARRAL	10.5 M	51.1 M	4:1
REDEYE	170.3 M	2,349.4 M	13:1
MLRS	13.8 M	508.5 M	36:1
PATRIOT	94.4 M	2,463.3 M	26:1
SRP TOTALS	393.0 M	8,730.2 M	22:1

Figure 6. Stockpile Reliability Program (SRP)

Over the past 30 years, an SRP investment cost of $393M has resulted in cost avoidance of nearly $9 billion dollars, for a cost avoidance ratio of 22 to 1. In addition to shelf-life extensions, the surveillance aspect of the SRP makes a significant contribution to warfighting capability.

C. Missile and Rocket Surveillance Testing

The functional test program provides worldwide surveillance of user assets. When combined with laboratory testing of components and flight testing of the missiles and rockets, major warfighting benefits accrue. These include: (1) hardware reliability is assessed against requirements; (2) stockpile performance trends are detected; and (3) defective hardware is purged from the inventory. Over the past 10 years, defective hardware detected and removed from the inventory, ranged from 1 percent for HELLFIRE up to 12 percent for HAWK. In the process, more than 40 major problems (e.g., battery failures and propellant unbonding) have been surfaced and corrected for the entire stockpile. As hardware is processed through surveillance vans and missile facilities throughout the world, defective hardware is detected and purged from the inventory. The soldier has increased combat capability and confirmed safety and reliability for his assets. Unfortunately, funding for SRP has declined dramatically the past few years, putting all the aforementioned program benefits at risk. New, cheaper remote monitoring technology may help offset a portion of the budget reductions. Some of these remote monitoring programs are discussed in the next section.

IV. NEW TECHNOLOGY CHALLENGES

The United States Army has depended on new technology to provide weapon system superiority since the beginning of the Cold War. The Cold War ended, resulting in a drastic reduction of Army research, development, and procurement dollars. Insertion of new technology is now viewed as a way to save precious Army dollars and enhance the performance of existing weapon systems. Emerging advances in simulation and hardware-in-the-loop techniques, remote monitoring systems, and PEMs will be helpful in achieving these expectations.

A. Simulation

The U. S. Army Missile Command has traditionally accepted production lots of small missiles through live firing of production samples. Commonly known as "Fly-To-Buy (FTB)" testing, a multi-level sampling plan is used to determine lot acceptability and provide benefits as described in Figure 7. One MICOM system reported a 7 point increase in reliability by finding and fixing hardware defects discovered during FTB. This translated into $175 million in improved cost effectiveness for our soldiers.

DEFINITION

- Final QA Test Used To Accept Lot
- Small Statistical Sample After Factory Tests
- Verifies Final Assembly & Integration of Complete Round and Uses Actual Environments
- Provides Trends in Performance, Reliability and Safety

MICOM POLICY 702-5

Decision Criteria

- FTB Unit Cost Threshold < $200K FTB Cost <5% Procurement Cost
- Production Rate > 50 Per Month

Adjusting FTB

- No Failures
- In-Control Processes
- Contractor Consistently Producing Good Hardware
- Contractor is (CP)2

BENEFITS

- Increases Confidence in Product Quality
- Identifies Problems with Government Furnished Property
- Allows Immediate Corrective Action
- Results in Improvements In Hardware Quality and Reliability
- Design/Process Deficiencies
- Potential for Stockpile Purification

Figure 7. Fly-To-buy (FTB) Definitions and Benefits

The HELLFIRE II program, for example, uses a 4-4-2 sampling plan. Figure 8 shows a comparison of the HELLFIRE II FTB program

versus that proposed for HELLFIRE LONGBOW. For the HELLFIRE II FTB, 12 random missiles are selected from a month's production lot for the sample set, which includes 2 contingency rounds. The sample set undergoes functional testing, environmental and dynamic testing, and is then destructively flight tested. Four missiles of the sample set are initially fired. If there are no failures, the lot is accepted. Two failures and the lot is rejected. One failure, and the test continues with another group of four missiles flown. Again, if all four of the next group pass, the lot is accepted. Two failures result in lot rejection, and one failure requires the remaining two missiles be flown. If either of the two remaining missiles fail, the lot is rejected. The two contingency missiles are used to replace any missile that was determined to be a "no test".

While this traditional FTB testing has proven very effective in finding production deficiencies (Fig. 9), the cost involved, especially for more complex and expensive missiles, can be prohibitive. HELLFIRE II missiles cost roughly $47,000 a piece and a minimum of 4 and maximum of 12 missiles must be flown. Therefore, between $188000 and $564000 in assets will be destroyed, and test/range costs can be in the tens of thousands of dollars.

Fly-To-Buy (FTB)

Smp	Ac	Con	Rej
4	0	1	2
4	1	2	3
2	2	-	3

ADVANTAGES

- Exercised at actual environments (Temp, Vib, etc.)
- One-shots tested

DISADVANTAGES

- Destructive
- Costly
  - Expending hardware
  - Test costs
- Limited sample size

Simulation

Smp	Ac	Con	Rej
6	0	1	2
6	1	2	3
3	2	-	3

ADVANTAGES

- Non-destructive
- Multiple test scenarios
- Larger sample size
- Repeatable tests
- Lower test costs
- Dedicated facility

DISADVANTAGES

- One-shots not tested
- Not exercised at actual environments

Figure 8. Fly-To-Buy (FTB) Versus Simulation

STINGER	MLRS
-Gripstock Grounding -Launch Motor Squib Leaf Spring -BCU Welds -Blocked Tubes -Fuze Launch Switch Bonding Proc -Miswired Umbilical Squib -Gas Umbilical Leak	-Tube Cover Strikes -Loose Rocket Pod Retainer Pins -Spin Lug Failures -Shorted Pod Harness -Fin Restraint Crimping Problem -Rocket Motor Weight Variation -Grenade Dud Rate
TOW	**HELLFIRE**
-Motor Burn Through -Wire Breaks -Missile Control Lockup -Missile Pitchdown Bias -Airbursts (Warhead Problem)	-Gyro Squib Short -Seeker Bearings -Pitch Gyro Pot -Actuator Cold Solder Joint -Pot Wiper Contamination -Accumulator Squib

Figure 9. Problems Identified During FTB

Because the newly designed Hellfire Longbow missile will be much more costly than HELLFIRE II, the Air-to-Ground Missile System (AGMS) project office tasked the MICOM RDEC and the TECOM Redstone Technical Test Center (RTTC) to explore other test alternatives. In response, RDEC and RTTC proposed the Millimeter Wave Simulation/Test Acceptance Facility (STAF) which uses extensive simulation to provide a continued high confidence level for production lot acceptance testing, with a significantly reduced number of traditional destructive flight tests. The following description of the STAF facilities is from an article by Johnson and Ray (7). The STAF will functionally test a random selection of production missile rounds in a real-time, non-destructive, Hardware-in-the-Loop (HWIL) simulation. Production missiles containing tactical seekers, guidance electronics, inertial navigation systems, warheads, squibs, motor, and control actuators, will be tested in a bunker by remote control. Missile flight dynamics are simulated using a six degree of freedom digital model of the missile airframe running in real-time. A real-time data collection system will store missile "flight" data from the simulated launch to simulated target impact. Expected benefits from simulation/HWIL testing are shown in Figure 10.

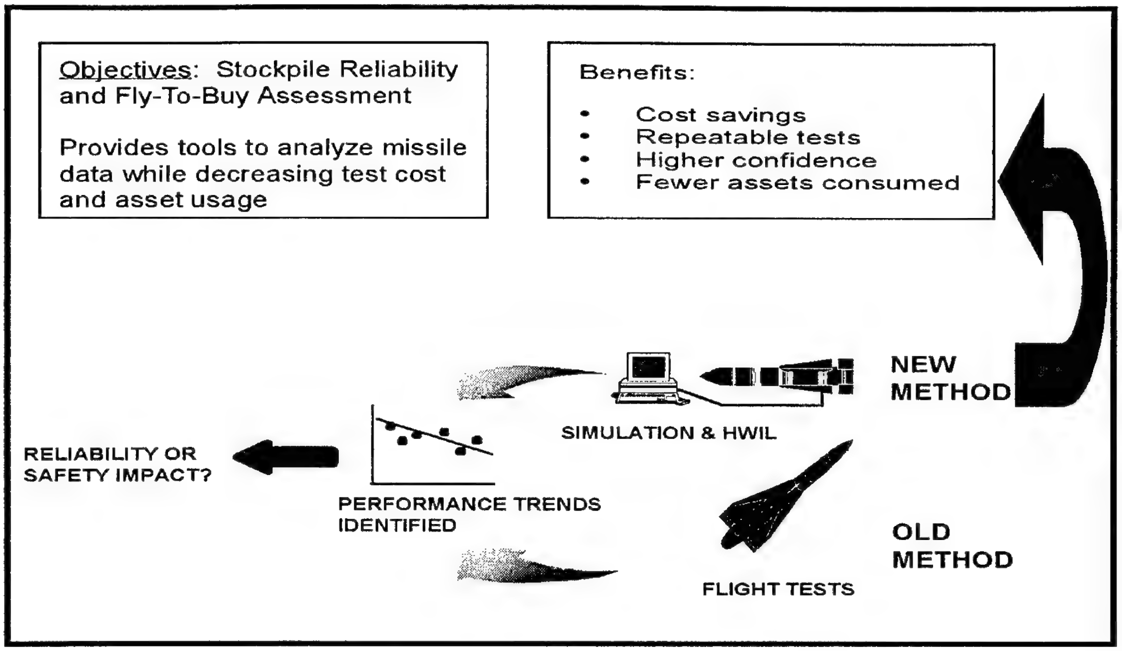


Figure 10. Simulation and HWIL Benefits

The STAF testing of selected production samples includes a combination of open and closed-loop testing to fully characterize the missile under test. The open-loop testing involves checking the control actuator system, the inertial measurement system and the end-to-end RF chain. The closed-loop testing involves simulating in-band threat and background scenery, real-time three-axis motion in pitch, yaw, and roll and injected inertial measurement data until simulated target impact.

The STAF testing allows real-time flight dynamics, real-time threat and background scene generation, and comprehensive data collection to the point of simulated target impact. The STAF is also capable of performing all tests under extreme temperature conditions to simulate various climates.

To assure the integrity of the STAF testing, plans call for live firing four missiles per year. This will allow the effectiveness of the STAF testing to be evaluated and one-shot devices to be fired. In addition to missile acceptance testing, the STAF can be used to check potential hardware and software upgrades and other modifications.

A cost trade-off analysis was performed comparing the STAF facilities versus traditional FTB testing (6):

> "The results of the cost tradeoff, using conservative values result in a cost avoidance of at least $5M per year, with potential of up to $10M per year."

This analysis indicated a total facilities cost payback period of less than a year.

The major drawback to STAF lot acceptance testing is its inability to test one-shot devices. The firing of squibs, thermal batteries, warheads and rocket motors cannot be simulated. The only known effective way to test these devices is by destructive testing. The Longbow prime contractor and the government have a real challenge assuring these devices are good prior to government acceptance of hardware. The annual live firing of the four samples will help, but this is an extremely small sample size. As the missiles are produced, only very high quality one-shot devices can be allowed in the production process. After the missiles are accepted into the Army inventory, stockpile reliability assessment becomes important. Some remote monitoring technology, discussed in the next section, should be very helpful.

B. Remote Monitoring Systems

The Army has been researching the use of MEMS technology, along with satellite transmission, to enable remote monitoring of military assets (Fig. 11). The ability to gather storage and environmental data from a remote site not only saves time and money, but allows maintenance schedules to be based on actual data. The MARMS was successfully completed in August 1996, and the follow-on SMART system is currently being pursued by the Army.

The MEMS concept is a new form of micro-fabrication of electromechanical sensors directly on a substrate. The micro-fabrication process creates micro-miniature movable machine elements that can be utilized on single microchips as sensors. The sensors that the Product Assurance Directorate is researching are devices that will be capable of detecting shock and vibration in all three axes.

The MARMS program, a prototype system developed under a contract funded by the PATRIOT Project Office, remotely monitored a missile canister and reported the environmental health (temperature, humidity, shock, and vibration) of the canister. The system could also transmit failure data to a remote location if a preset condition were exceeded (e.g. humidity over the preset limit).

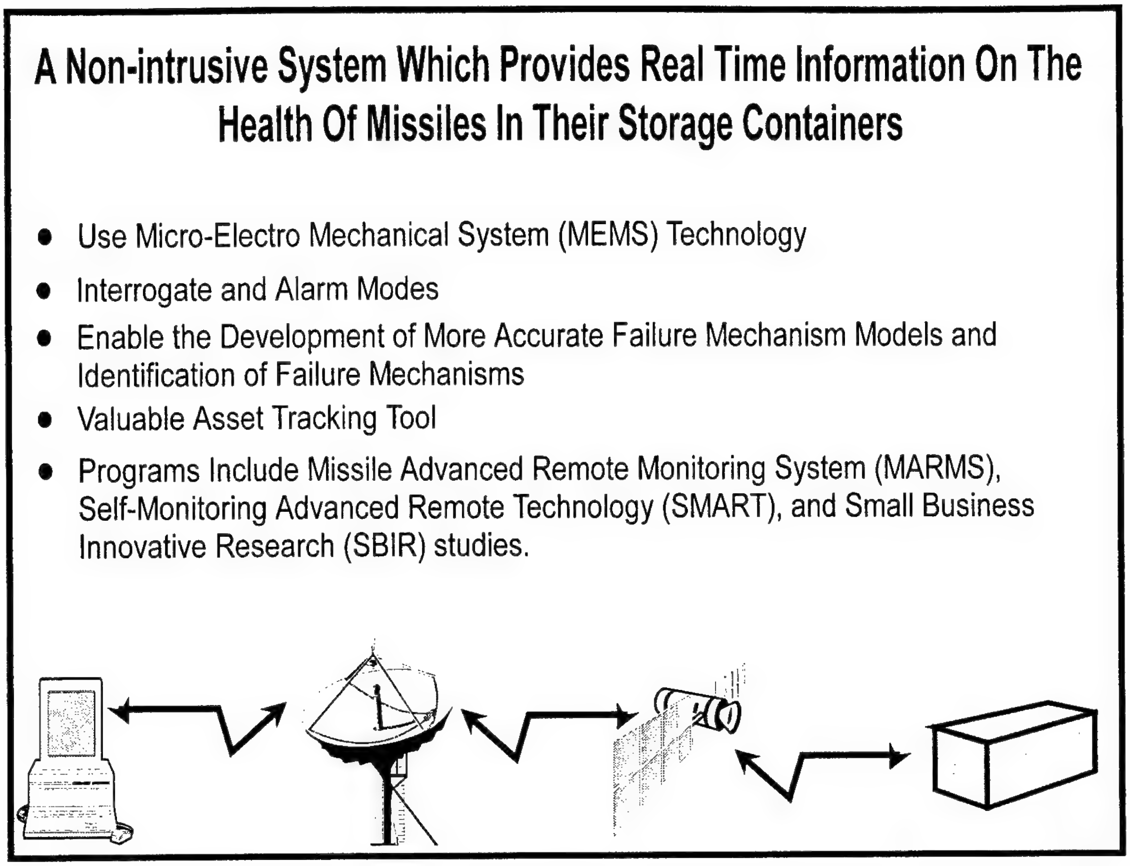


Figure 11. Remote Monitoring System

The objective of SMART is to develop and demonstrate a dual use remote monitoring system. The military application of SMART will be utilized for the assessment of the condition of fielded and stored tactical missiles and associated electronic equipment. The use of SMART by the military will reduce the cost of field support and will improve the ability to assess the readiness of fielded assets in real time. In the civilian application, SMART will be used to monitor the structural integrity and current highway conditions on bridges where remote monitoring is the only practical method for continuous assessment. The SMART technology efforts are being accomplished through the Technology Re-Invention Program (TRP) between the US Air Force and a consortium (Fig. 12) lead by Auburn University. MICOM is a non-voting participant in the consortium.

Participant	Consortium Position
Auburn University	Lead
Analog Devices, Inc.	Member
System Excelerator, Inc.	Member
Thomas Equipment Company	Member
Weld Star Technology, Inc.	Member
Northrop-Grumman	Member
Florida Department of Transportation	Non-voting Participant
US Army Missile Command	Non-voting Participant
US Air Force Materiel Command - Wright Laboratory	DARPA Technology Re-Invention Program (TRP)

Figure 12 - SMART Consortium Membership

C. PLASTIC ENCAPSULATED MICROCIRCUITS (PEMs)

As a result of acquisition reform, greater emphasis has been placed on commercial parts and processes. One such area is the use of commercial grade electronic parts (e.g., PEMs) instead of hermetically sealed military specification (MIL-SPEC) parts. For certain military applications, such as ground support equipment or test equipment, the performance impact may be low risk. However, in other applications, such as Army missiles, PEMs may not perform adequately in all the harsh environments experienced by the weapon systems. While supporting acquisition reform initiatives, the Army must ensure that weapon systems are developed and fielded that meet all system requirements, including long-term dormant storage. Some concerns with PEMs will be identified and then details will be provided of actions taken to address these concerns.

By way of background, PEMs are not new. They have been used very effectively in numerous commercial applications, such as automotive and computer. Their chief advantage is that they are less expensive than their military counterparts. What is new about PEMs is the emphasis within DOD to achieve costs savings by using them in weapon system designs. The SECDEF memorandum (1) encourages expanded use of commercial devices in military applications.

The MIL-SPEC environment is changing rapidly with influences from the commercial markets. Department of Defense (DOD) funding reductions have reduced the demand for MIL-SPEC parts. Consequently, fewer sources are interested in competing for this reduced market, and PEMs are being substituted for hermetically sealed MIL-SPEC parts. Because of the peculiar operating requirements for Army missiles, MICOM has raised concerns with unrestricted use of PEMs in MICOM systems. Figure 13 lists some concerns which were identified during a commercialization study of the JAVELIN missile system. The chief concern is missile reliability after long-term dormant storage in uncontrolled (harsh) environments. Insufficient data is available to address this concern. Because of a reduced interest by the commercial sector in hermetically sealed MIL-SPEC parts , obsolescence is a growing problem. The only replacement parts available in many applications are PEMs. Operating requirements, such as temperature range of PEMs, are not required to be as stringent as military requirements. During the production process for PEMs, normally there is much less parts testing and inspection than for hermetically sealed MIL-SPEC parts. Consequently, latent defects may be incorporated in large production lots of missiles. This may give rise to "hidden" costs that will not show up until items have been fielded. The cost of fixing a part problem increases significantly after production and fielding.

- Lack of Data to Support PEMs Performance in Uncontrolled Long-Term Storage
- Temperature Limits of Military Applications Generally Exceed Commercial Applications
- Reduced Parts Testing and Inspection
- Hidden Costs May Negate Any Potential Cost Savings

Source: Commercialization Study for the JAVELIN Missile System, May 1995, MICOM Systems Engineering & Production Directorate, Bob Gibbs, Doug Johnston, Jennifer Bishop, et al

Figure 13. PEM Concerns for Army Missile Applications

The Navy has expressed similar concerns (Fig. 14). This information was included in a Navy technical brief in May 1995. First, the design phase must consider the total life cycle environments (manufacturing, transportation, and storage), not just operating environments. Because many Army missile systems are treated as "wooden rounds", the first time that all systems are powered is during an actual mission. There are no periodic tests to determine overall readiness prior to pressing the launch

button. In the past, some commercial parts have been upgraded to military grade through screening. This is not possible with PEMs, especially with respect to temperature extremes. To achieve high quality/high reliability, plastic parts require special manufacturing processes. Obsolescence is also a concern to the Navy as is the selection of suppliers that have a proven capability to produce the highest quality PEMs.

- Design to Life Cycle Environment, Not Just to Mission
- PEMs Are Not Upgradeable to Military Operating Ranges (-55°C to +125°C) by Screening
- PEM Reliability May be Unsatisfactory for Long-Term Dormant Storage Systems
- Plastic Encapsulant Material Characteristics Require Special Manufacturing Processes
- Supplier Selection is Critical for Low Risk

Source: Dept of Navy Technical Brief-May 1995, Office of the Assistant Secretary of the Navy (Research, Development, and Acquisition), Deputy for Acquisition and Business Management

Figure 14. PEM Concerns for Navy Applications

This final chart provides a summary of MICOM's approach to addressing PEM concerns.

- Use PEMS Where Performance Characteristics Allow
- Search PEM Literature for Reliability Data
- Conduct Long-Term Storage Program
- Develop and Build an Environmental Test Chamber
- Plan and Execute an Accelerated Test Program

Figure 15. MICOM Initiatives to Address PEM Concerns

The PEM applications are increasing rapidly and undoubtedly will be increasingly used in military applications. Until performance characteristics of PEMs have been determined for environmental extremes, PEMs should only be used in low risk applications compatible with their capabilities (e.g., ground support equipment and test equipment). The MICOM continues to be involved, directly or indirectly, with the latest PEM research. To address specific missile concerns, MICOM has initiated several programs to assess potential risks. A plan is in place to develop and build an environmental test chamber which can subject the PEM devices to multiple environments simultaneously. This more accurately represents the real world life cycle and should provide valuable information for future decisions about PEM applications in missiles. Outlined below, a long-term storage assessment program is in its second year and will continue to provide data for several years.

D. PEM STORAGE ASSESSMENT PROGRAM

The PEM assessment program began because of reliability concerns associated with increased use of PEMs in DOD weapon systems. Army missile reliability is particularly at risk due to our unique requirement for long-term dormant storage in harsh environments. Since there is a lack of data on long-term dormant storage of PEMs in harsh environments, test programs are necessary to determine the risk of using PEMs in Army missile applications.

The results of the program may be used to predict stockpile reliability impacts and to better design PEMs and missiles for long-term dormant storage. For example, missiles may need to be stored in less harsh environments or be electrically tested periodically to drive out moisture and contaminants that may be

absorbed through the plastic coatings on the PEMs. Maintenance of missiles may be impacted - requiring replacement of PEMs after certain time intervals. Another desired outcome of the program is to validate accelerated aging models by comparing them with real-time aging test results.

Several test programs are under way (Fig. 16). Some of the programs include generic PEMs that may go into missiles, and some include PEMs that are now in weapon systems. These include some MICOM programs, Small Business Innovative Research (SBIR) with contractors, and industry/government joint programs (Figs. 16 and 17).

E. PEM ACTUAL AGING PROGRAMS - CD4011 and LM324

The CD4011 (quad nand gate) Actual Aging Program is a five-year program with parts from five manufacturers stored in five locations which are typical of real world, harsh environments. Parts are taken out of storage once each year for testing and returned to storage. The first annual test was performed in March 1996.

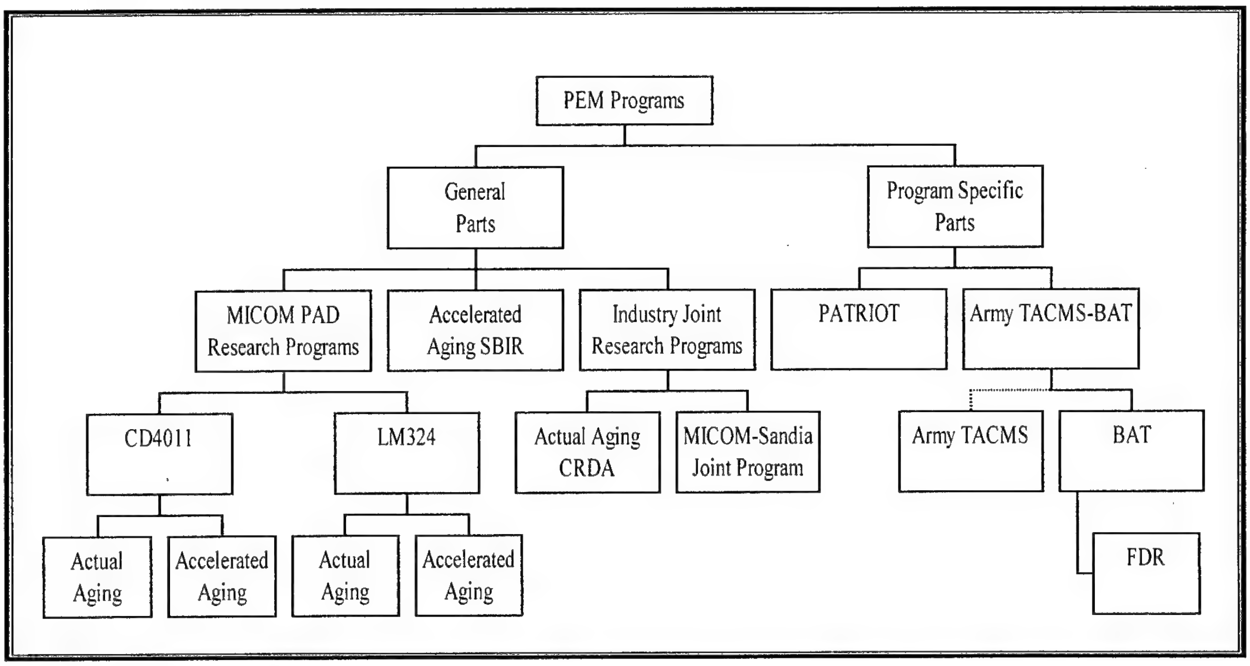


Figure 16. MICOM PEM Program Plan

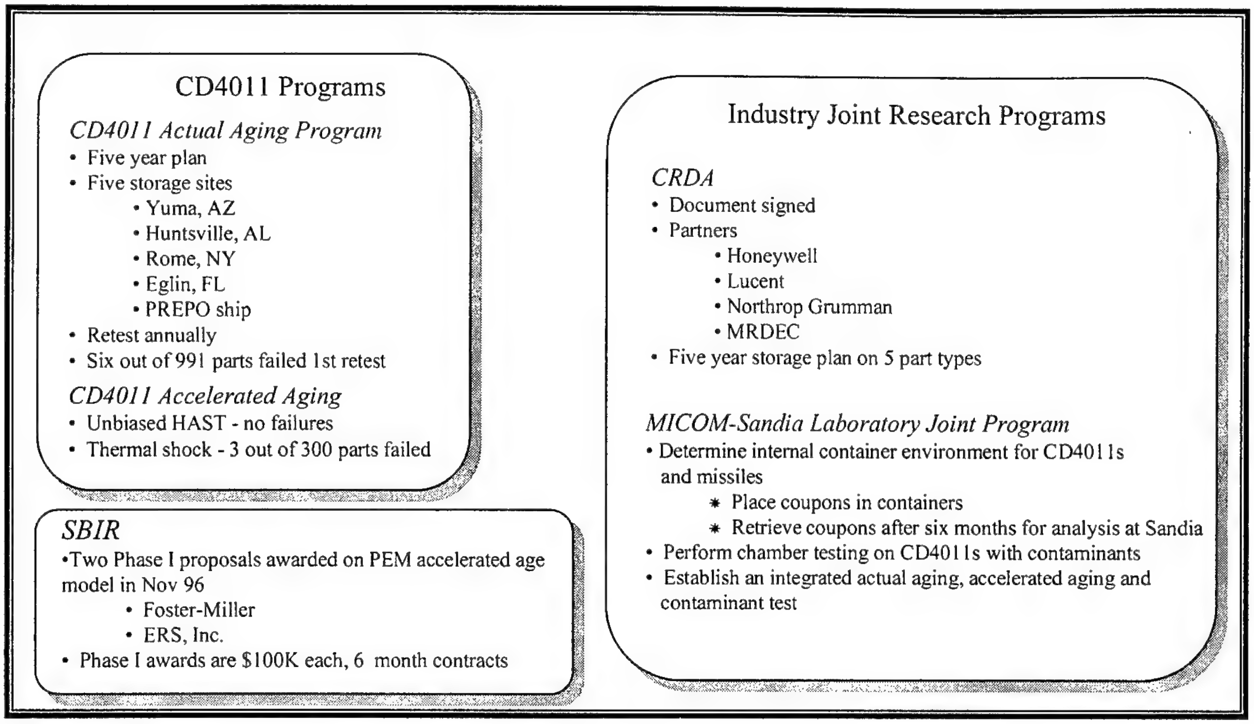


Figure 17. General Parts Program Description

There were 6 significant, but not catastrophic, electrical failures (991 parts tested). The parts remained in test to determine whether any degradation trends develop in the future. The second annual test is currently being performed.

The CD4011 Accelerated Aging Program consists of unbiased highly accelerated stress testing (HAST) and thermal shock testing. The unbiased HAST is complete and there were no failures. The thermal shock testing is complete and resulted in 3 failures out of 300 parts tested. Failure analysis on those failures is to be performed. A delamination analysis is also ongoing on the thermal shocked parts to determine the impact the amount of delamination has on part performance.

The LM324 (quad op amp) Actual Aging Program is a dormant storage program which uses parts surplus from the 1995 Defense Logistics Agency Plastic Package Availability Program. This program will compare different types of plastics on the same part type. The parts are planned to be placed in storage in April 1997.

F. PEM ACCELERATED AGING MODEL AND JOINT RESEARCH PROGRAM

Two SBIR Phase I proposals were awarded for the development of a PEM storage accelerated aging model in November 1996. Each award is for $100,000 with a 6-month performance

period. The Actual Aging Cooperative Research and Development Agreement (CRDA) includes Honeywell, Lucent (formerly part of AT&T), and Northrop Grumman. Each partner contributes materials or testing without exchanging funds. The parts are expected to be placed in storage in April 1997, and to be annually tested for five years.

The MICOM-Sandia Laboratory Joint Program currently consists of using copper-silver coupons to determine the environment inside missile containers. The coupons should be stored in July 1997. We are also working with Sandia to conduct a test involving the exposure of PEMs to industrial contaminants. All of these programs are ongoing to assess the risk of using PEMs in missiles subject to long-term dormant storage in harsh environments. The program will be modified as PEM design and manufacturing processes change and as more information on military applications of PEMs becomes available.

V. SUMMARY

The trend for military appropriations for the foreseeable future is downward. Innovative approaches must be developed and implemented to offset this reduction in funding if our 21st Century soldiers are to be the best equipped in the world. From both a procurement and technical standpoint, there are many new initiatives that can help achieve this objective. Acquisition Reform, with emphasis on PBC, and the SPI, if implemented properly, should reduce the cost of future weapon systems. Wise applications of plastic parts, simulation, and SMART stockpile reliability programs can also be significant contributors. The challenge to the government procurement and technical community is to implement the acquisition reform initiatives and to apply the technological advances with appropriate caution to prevent any performance degradation. Our soldiers must have weapon systems they can bet their lives on!

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